Progress in Developing Close-Packed X-ray Microcalorimeter Arrays of Mo/Au Transition-Edge Sensors with Bismuth Absorbers

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Why Mo/Au?

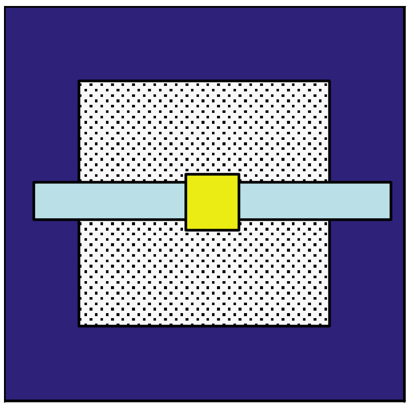
- Since most superconductors have too high a T_c to be of use in a microcalorimeter, it is common to use a bilayer of normal and superconducting films and the adjust the thicknesses of the two layers to tune T_c.

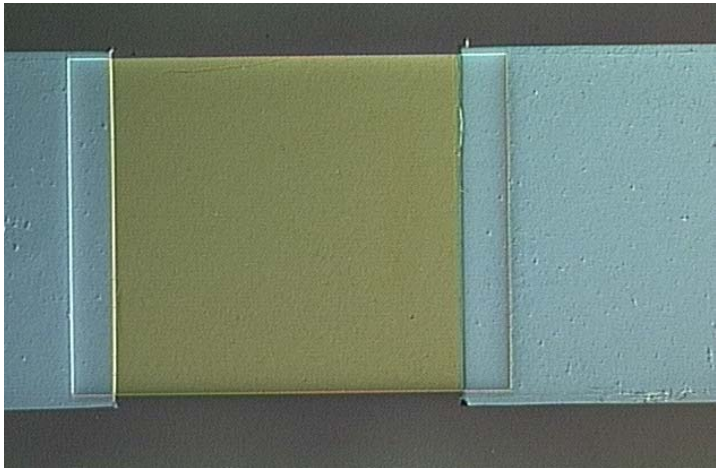
- The choice of metals is guided by the need to survive the temperature changes and chemical exposures to which the devices will be exposed en route to becoming a focal plane array, as well as optimizing the superconducting properties.

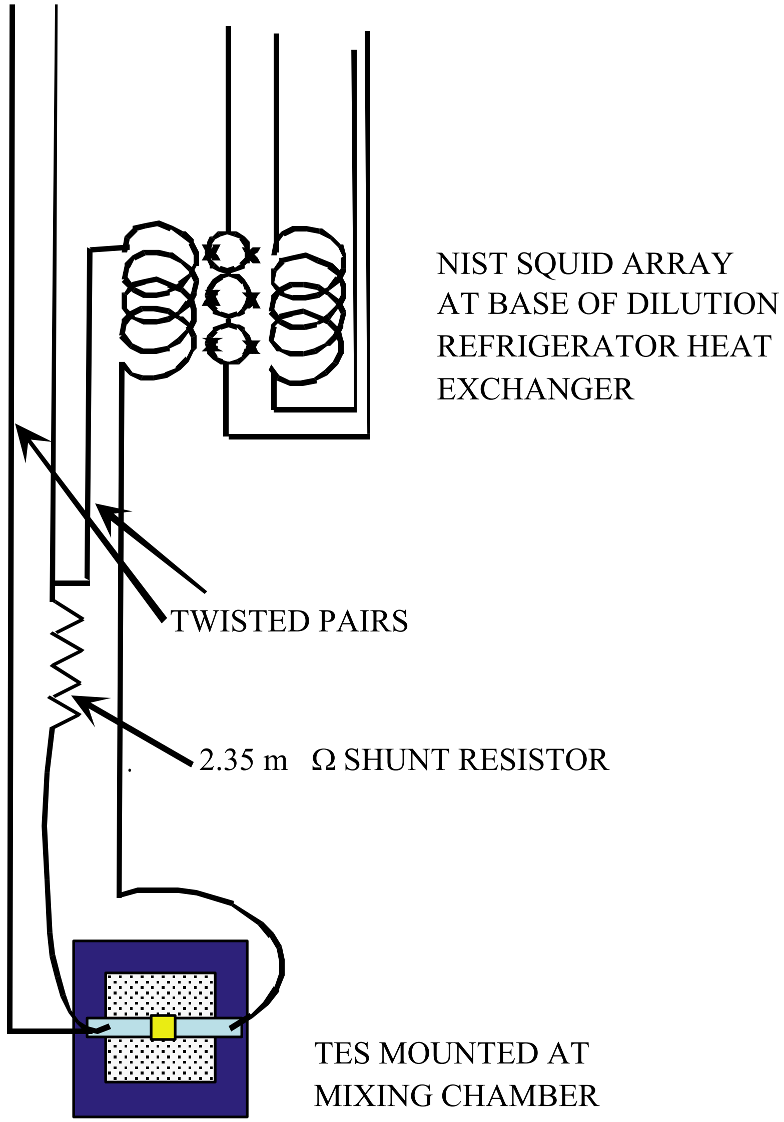
- At Goddard, we have been developing bilayers composed of molybdenum and gold.
    - Immiscible below 300 ºC, low diffusion even at elevated temperatures
    - Corrosion resistant
    - Seen as robust system for integration with array micromachining

Basic test cells:

- Mo/Au TES bilayer, Au extends over Mo at edges by several μm
- Nb leads
- 0.5 μm silicon nitride membrane
- Range of membrane sizes and TES areas



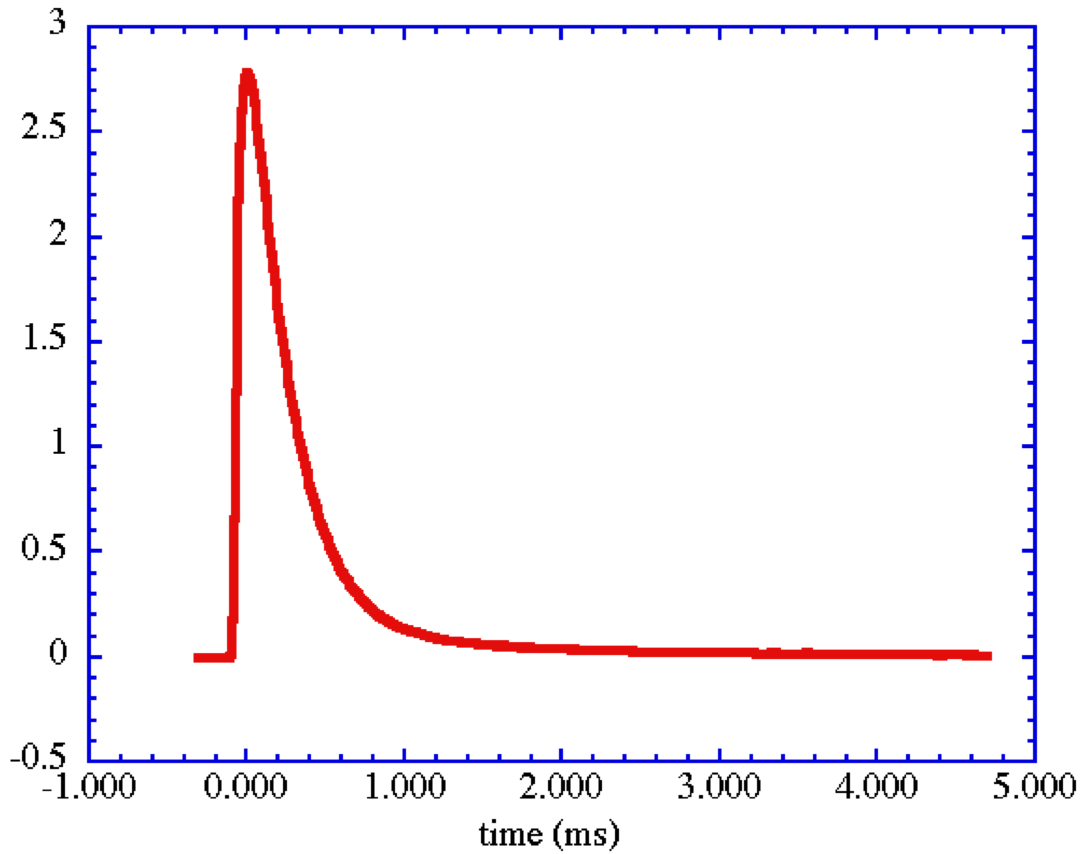


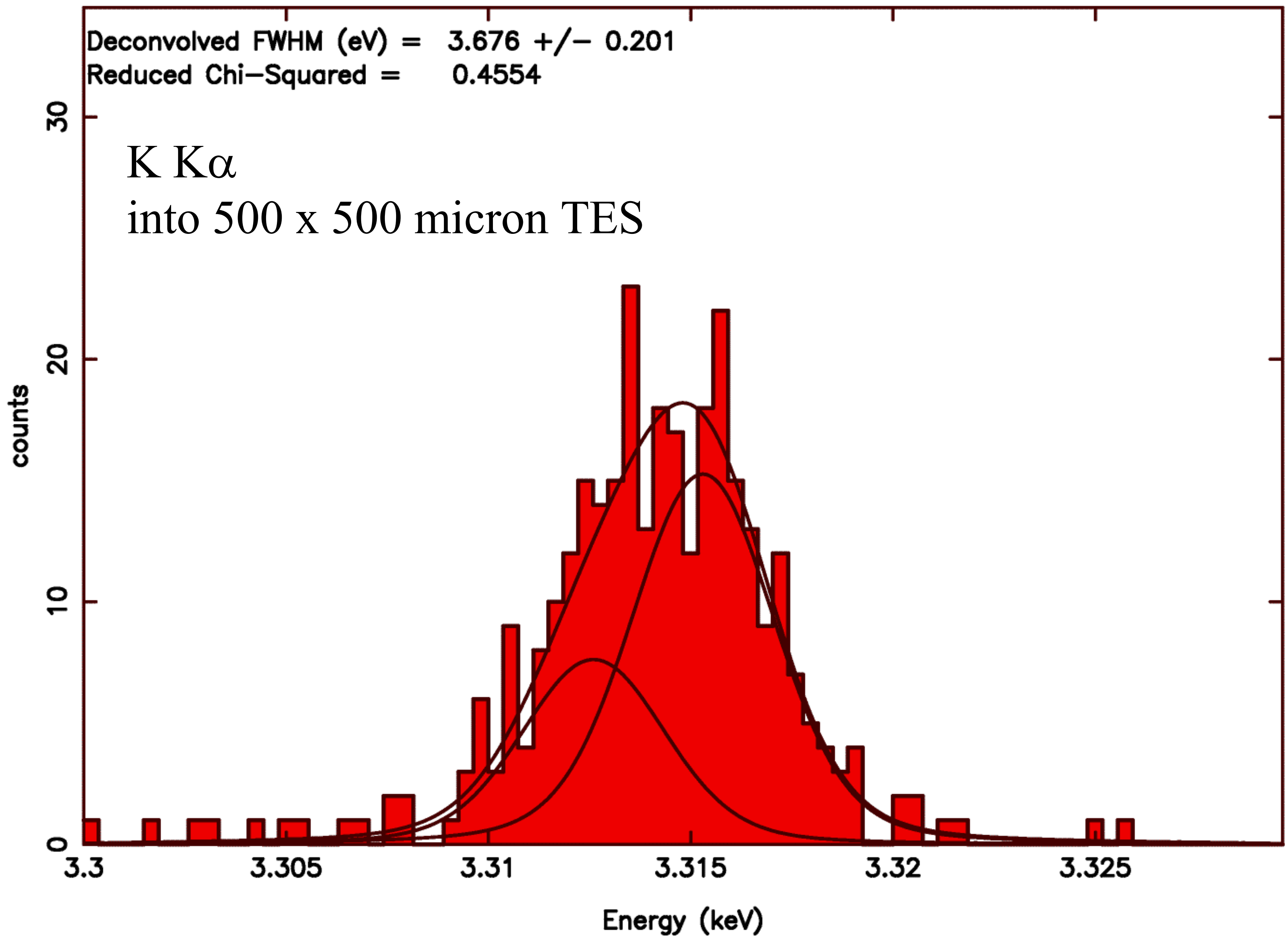


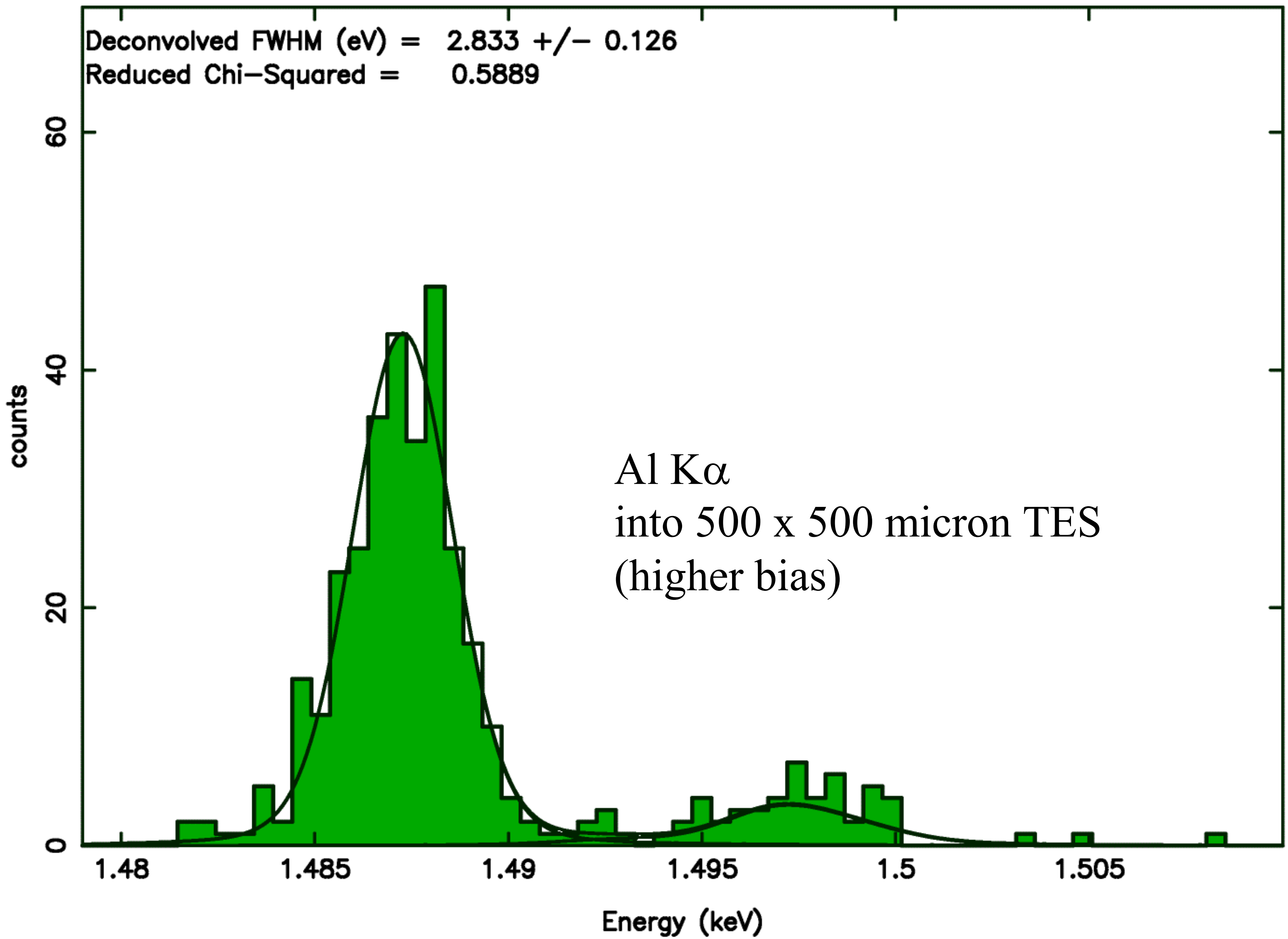
Single pixel TES results:

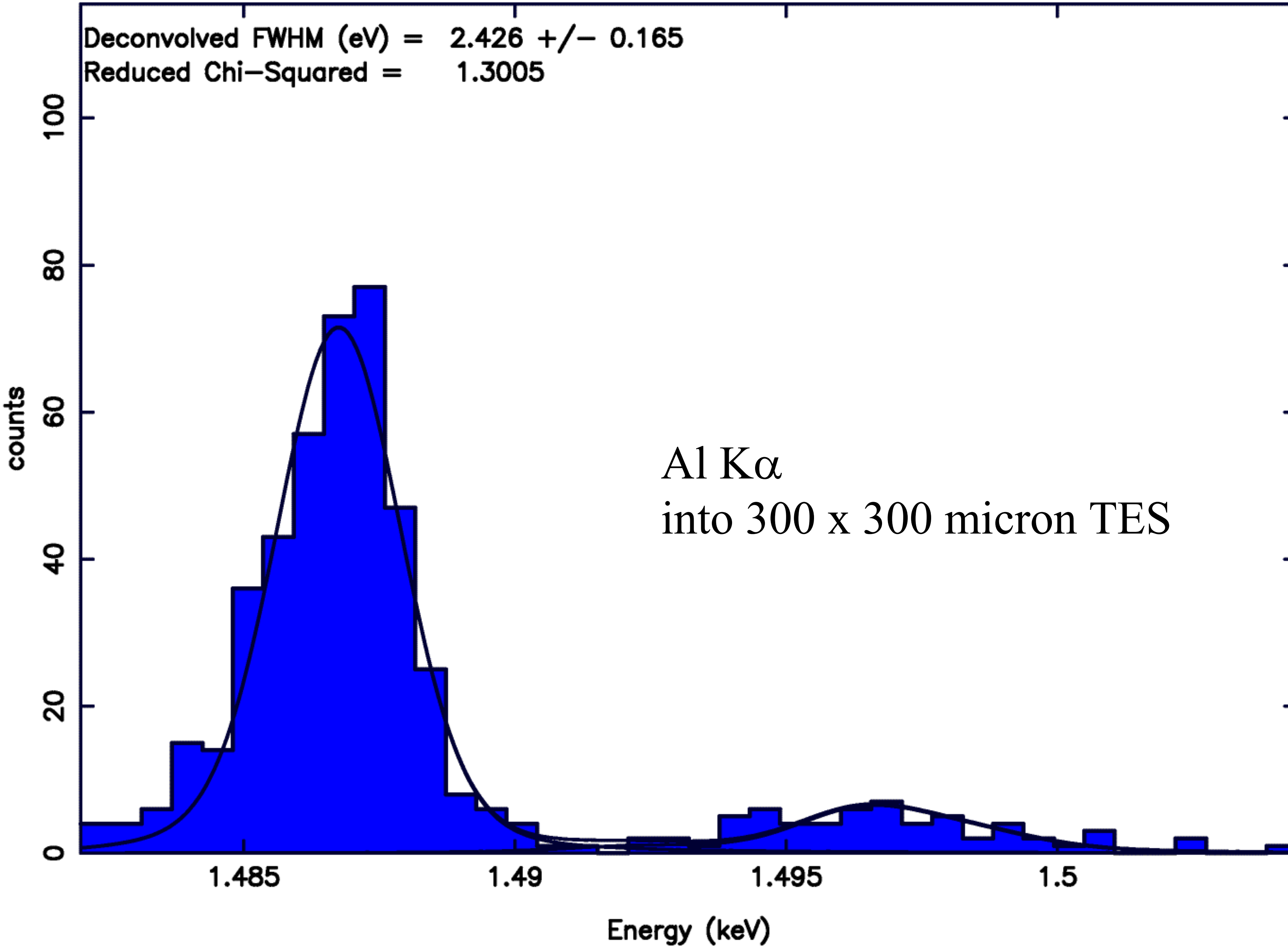
• Excess noise (above theoretical predictions) seen and being characterized; does not scale as flux flow noise

• Nevertheless, we have extremely encouraging results

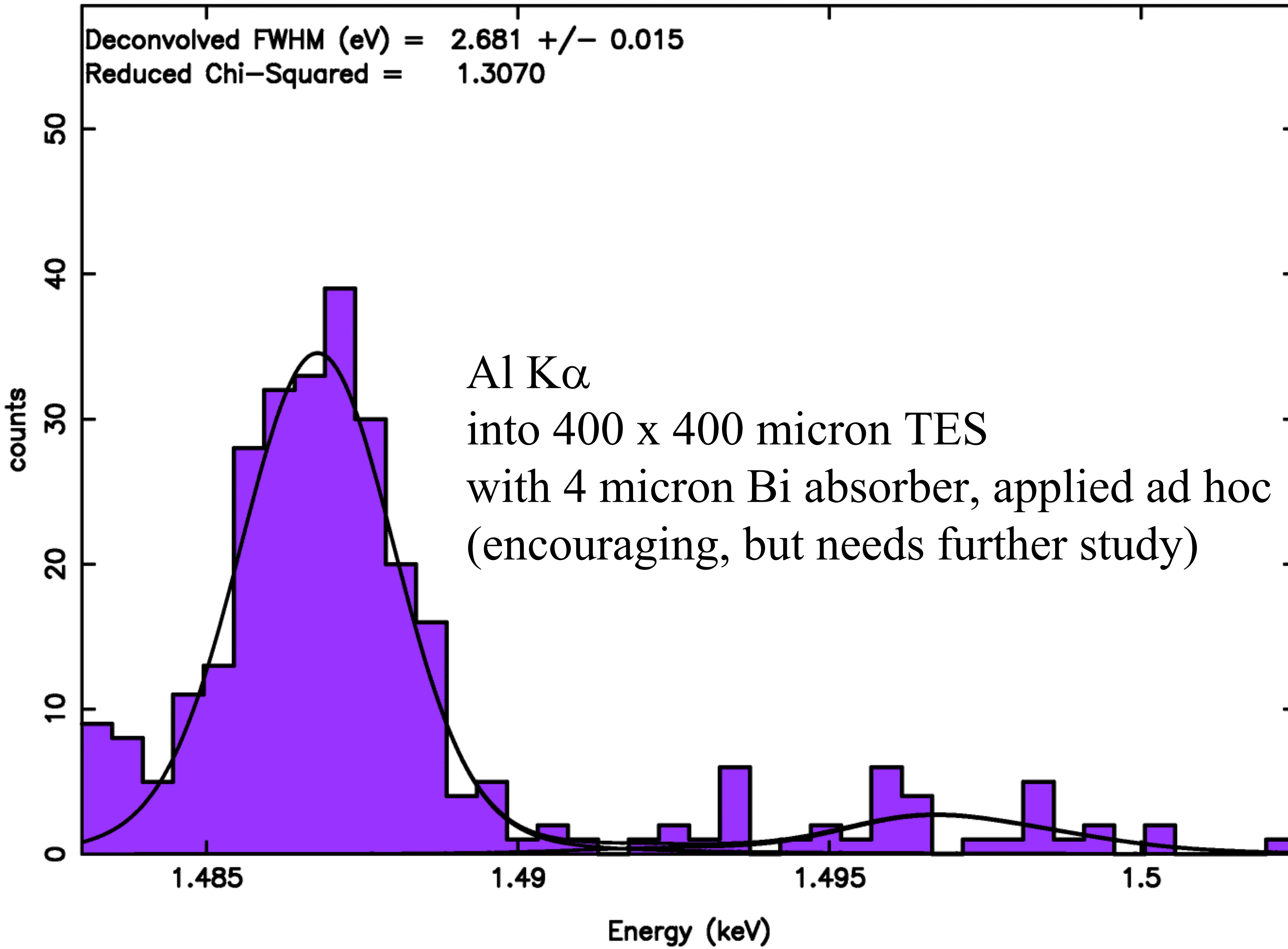



Deconvolved FWHM (eV) = 3.676 +/- 0.201
Reduced Chi-Squared = 0.4554
K Kα
into 500 x 500 micron TES
counts
0
10
20
30
3.3
3.305
3.31
3.315
3.32
3.325
Energy (keV)


Deconvolved FWHM (eV) = 2.833 +/- 0.126
Reduced Chi-Squared = 0.5889
Al Kα
into 500 x 500 micron TES
(higher bias)
counts
0
20
40
60
1.48
1.485
1.49
1.495
1.5
1.505
Energy (keV)



Deconvolved FWHM (eV) = 2.426 +/- 0.165
Reduced Chi-Squared = 1.3005
counts
0
20
40
60
80
100
1.485
1.49
1.495
1.5
Energy (keV)
Al Kα
into 300 x 300 micron TES

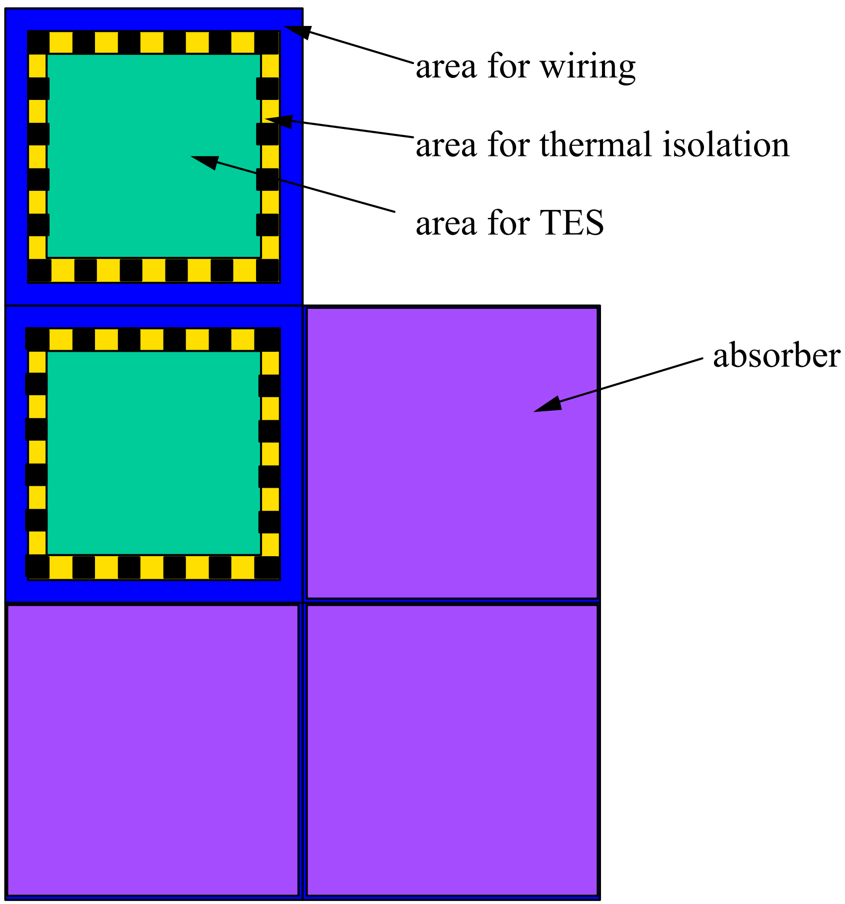

Deconvolved FWHM (eV) = 2.681 +/- 0.015
Reduced Chi-Squared = 1.3070
Al Kα
into 400 x 400 micron TES
with 4 micron Bi absorber, applied ad hoc
(encouraging, but needs further study)
counts
0
10
20
30
40
50
1.485
1.49
1.495
1.5
Energy (keV)

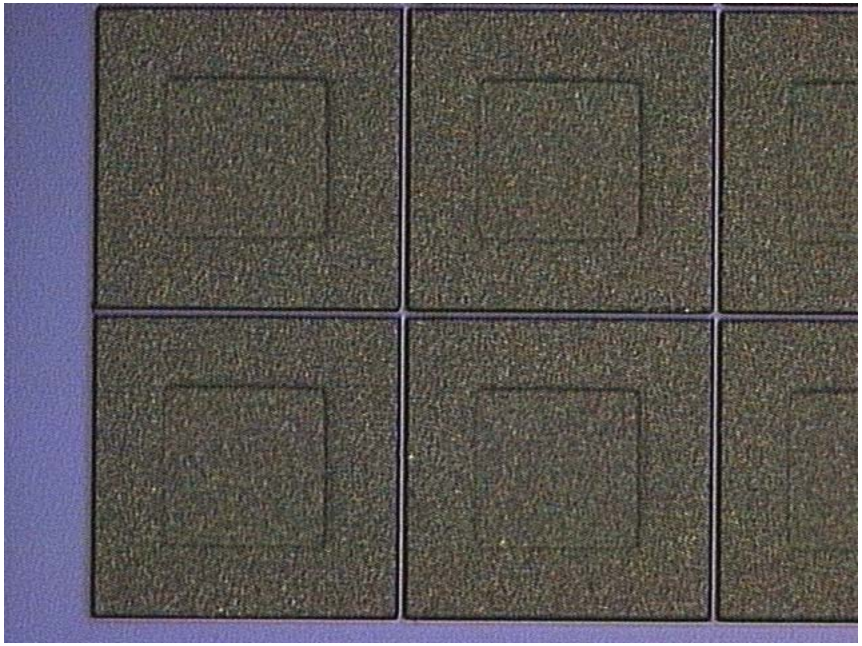
Compact pixels:

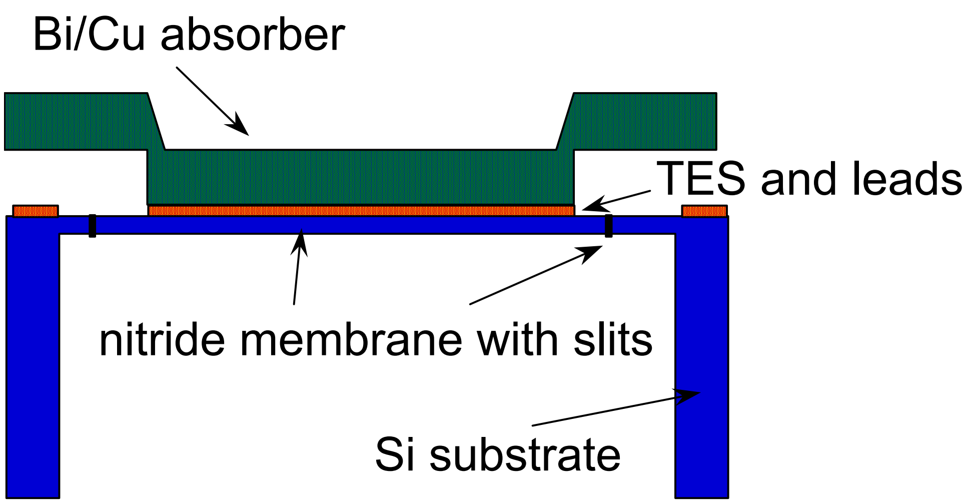
- In order to be truly suitable for imaging spectroscopy, TES calorimeters need to be arrayed with a pixel size and focal-plane coverage commensurate with the telescope focal length and spatial resolution.

- Since this requires fitting the TES and its thermal link, a critical component of each calorimeter pixel, into a far more compact geometry than had previously been investigated, we have begun to address the fundamental scaling laws in pixel optimization.

Scheme for high filling fraction

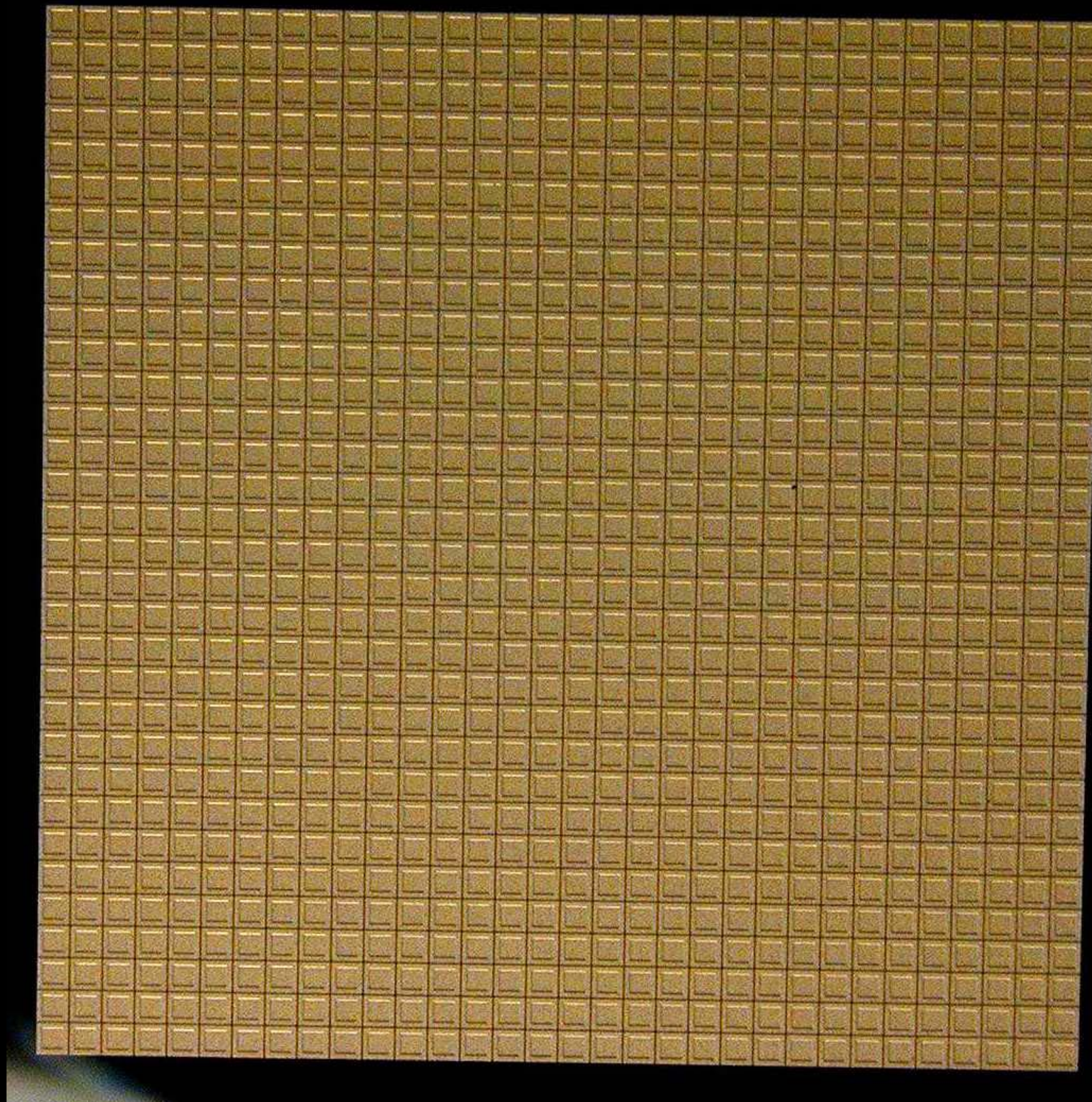




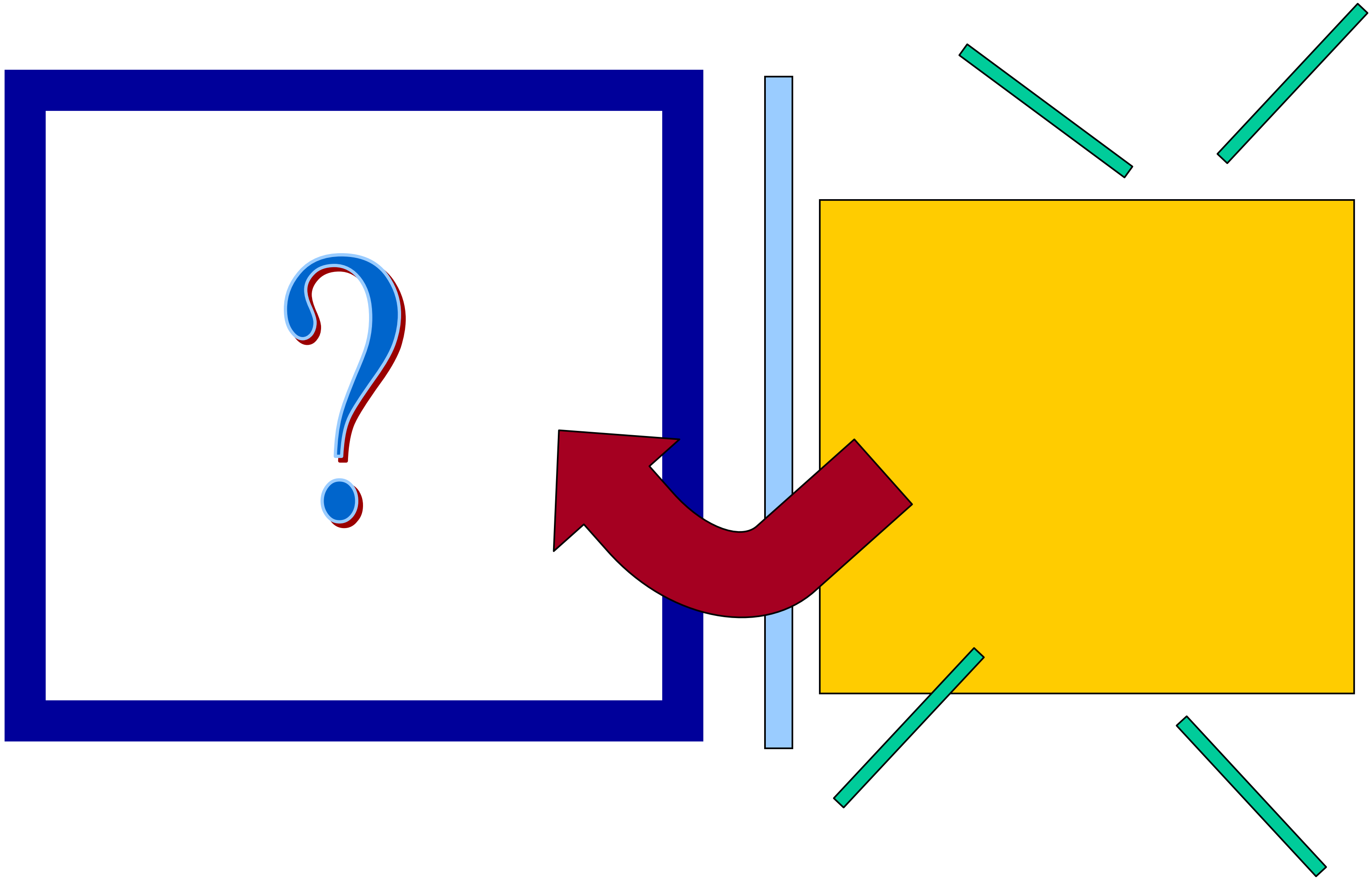


absorber is not part of the pixel area budget

32 x 32 array of overhanging bismuth absorbers



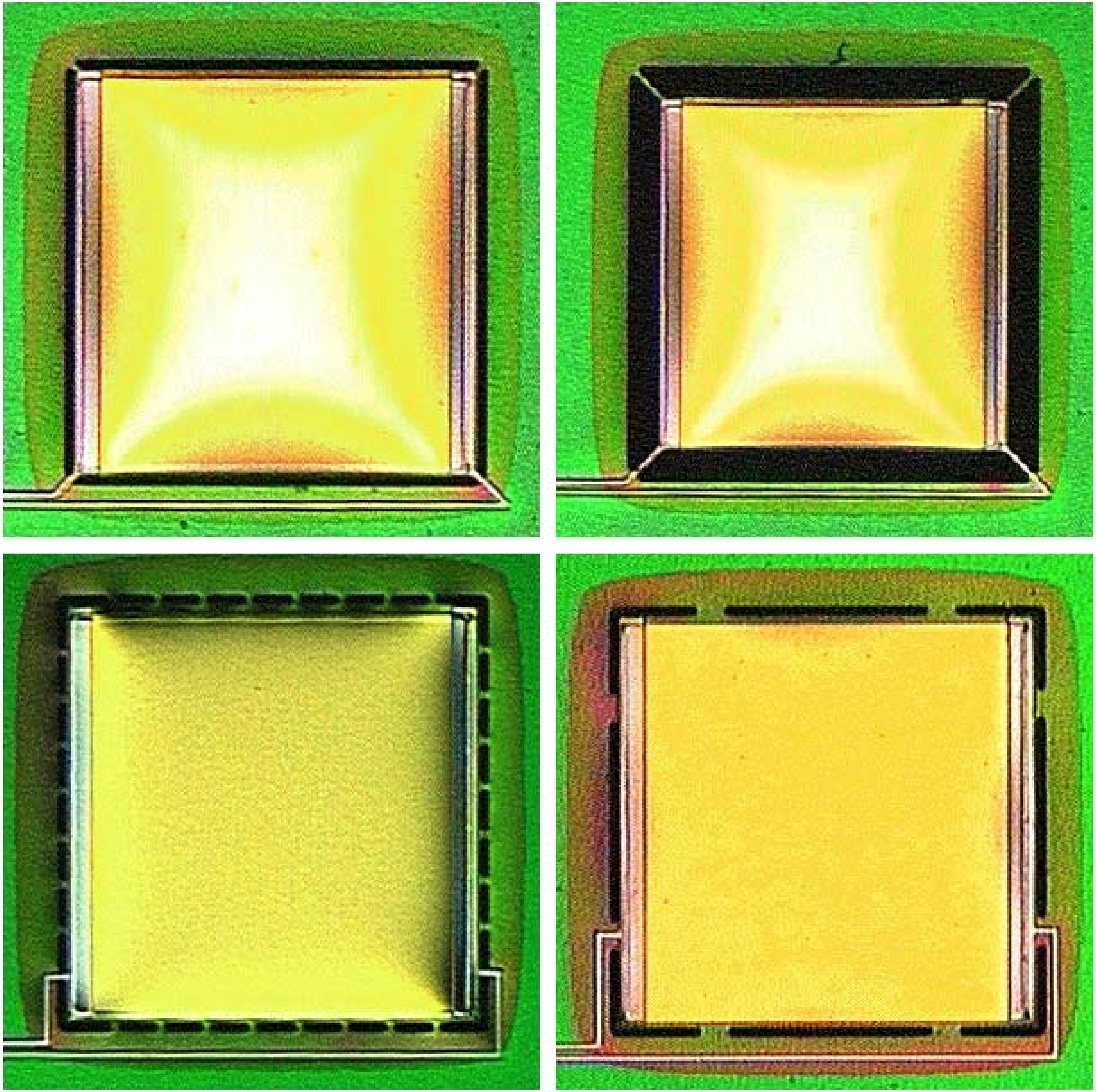
How do we best allocate the available space among the TES, the link, and channels for wiring traces? What is the smallest area that the link can occupy and still function?

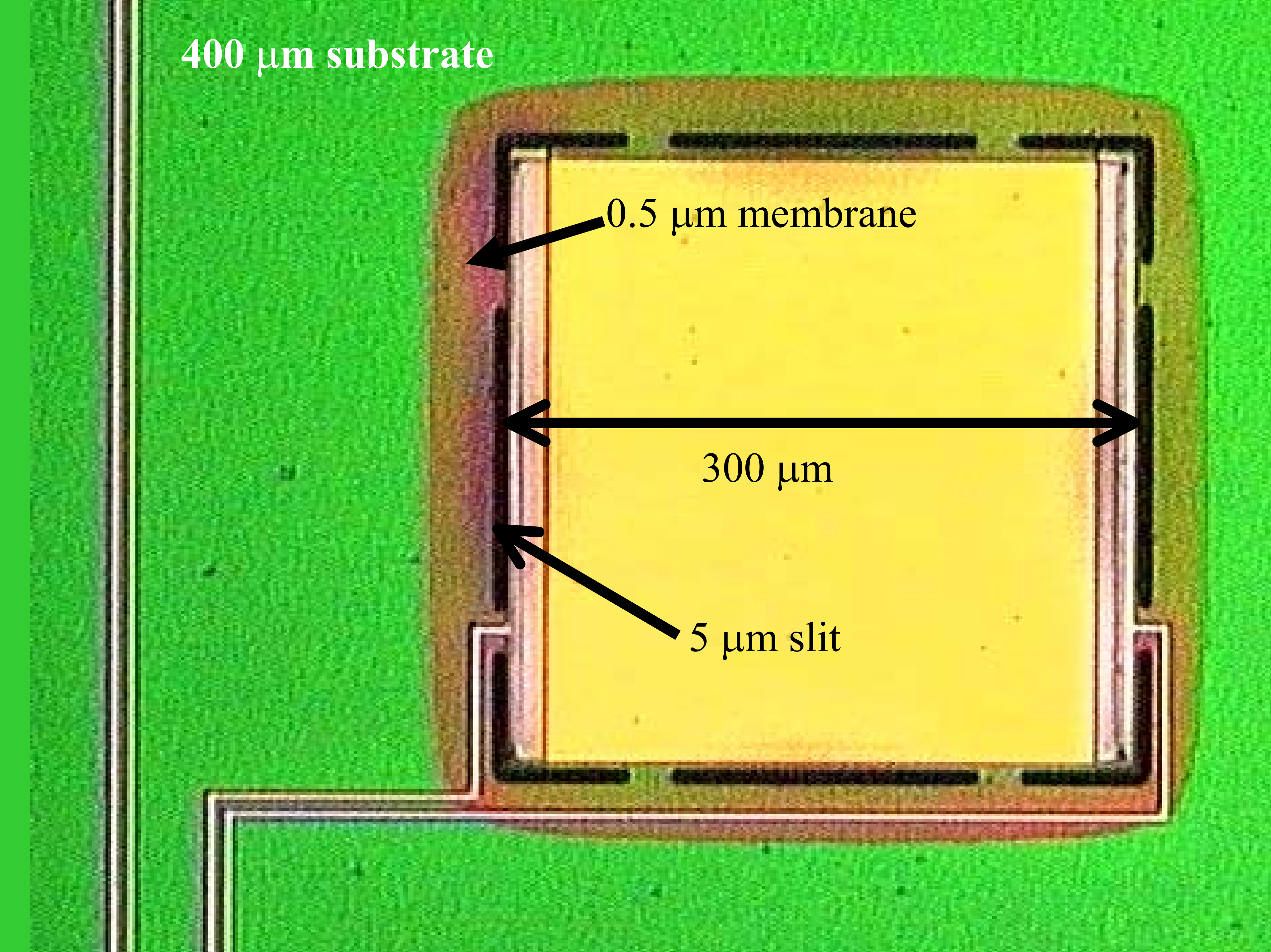


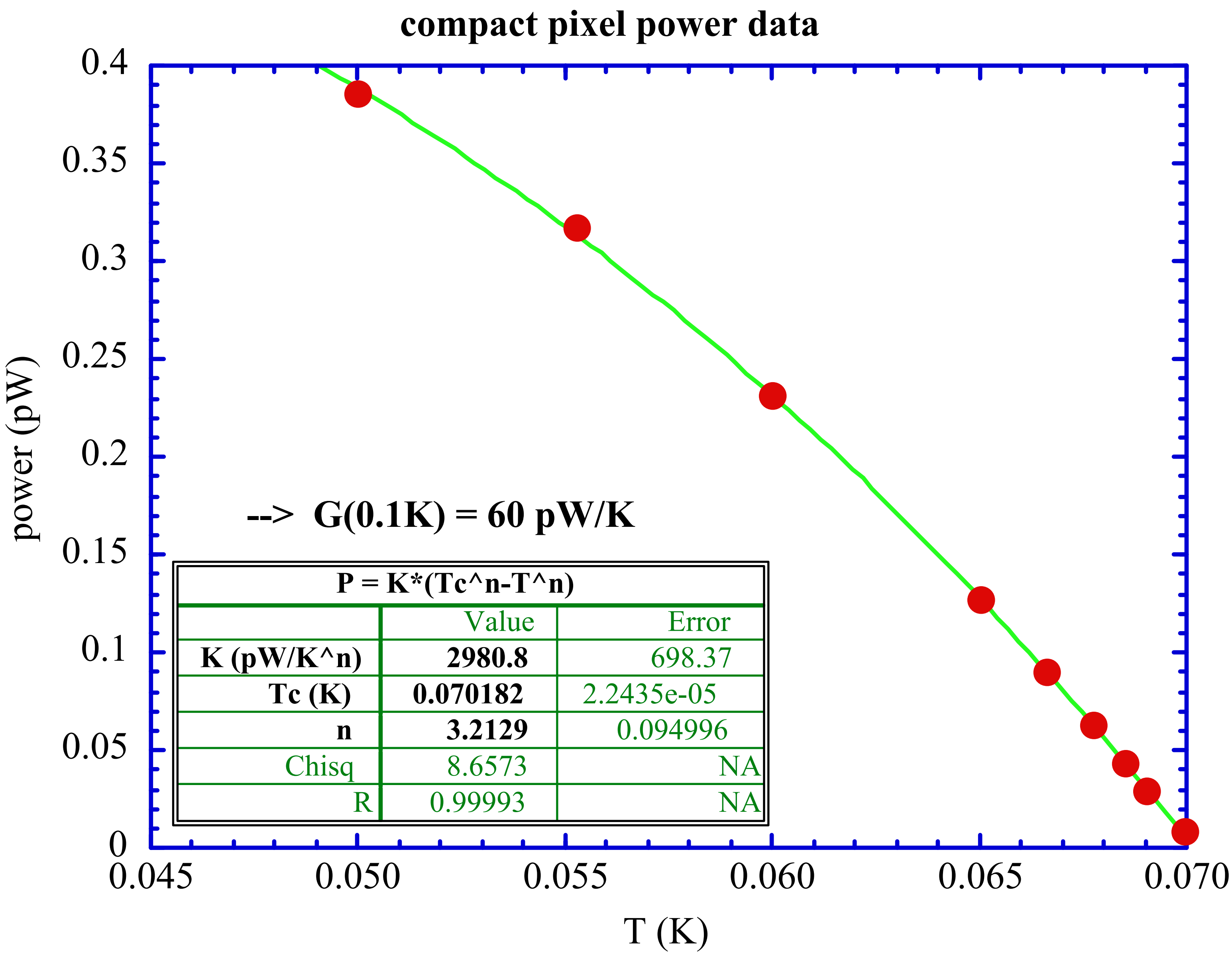
guiding design philosophy:

- use as little area as possible for the weak links, thermal busses, and electrical contacts
- use remaining area for TES
  - speed
  - noise

scale of weak links: At low temperatures, the phonon mean free path in an insulating membrane exceeds the sample dimensions. Surface scattering dominates, and if the surface is smooth and free of defects the specular limit can be reached. In the specular limit, energy transport scales like radiative transfer. Only the cross-sectional area, and not the length, determines the thermal load. We had already seen such scaling in the mm scale membranes, but would it break down on short length scales?



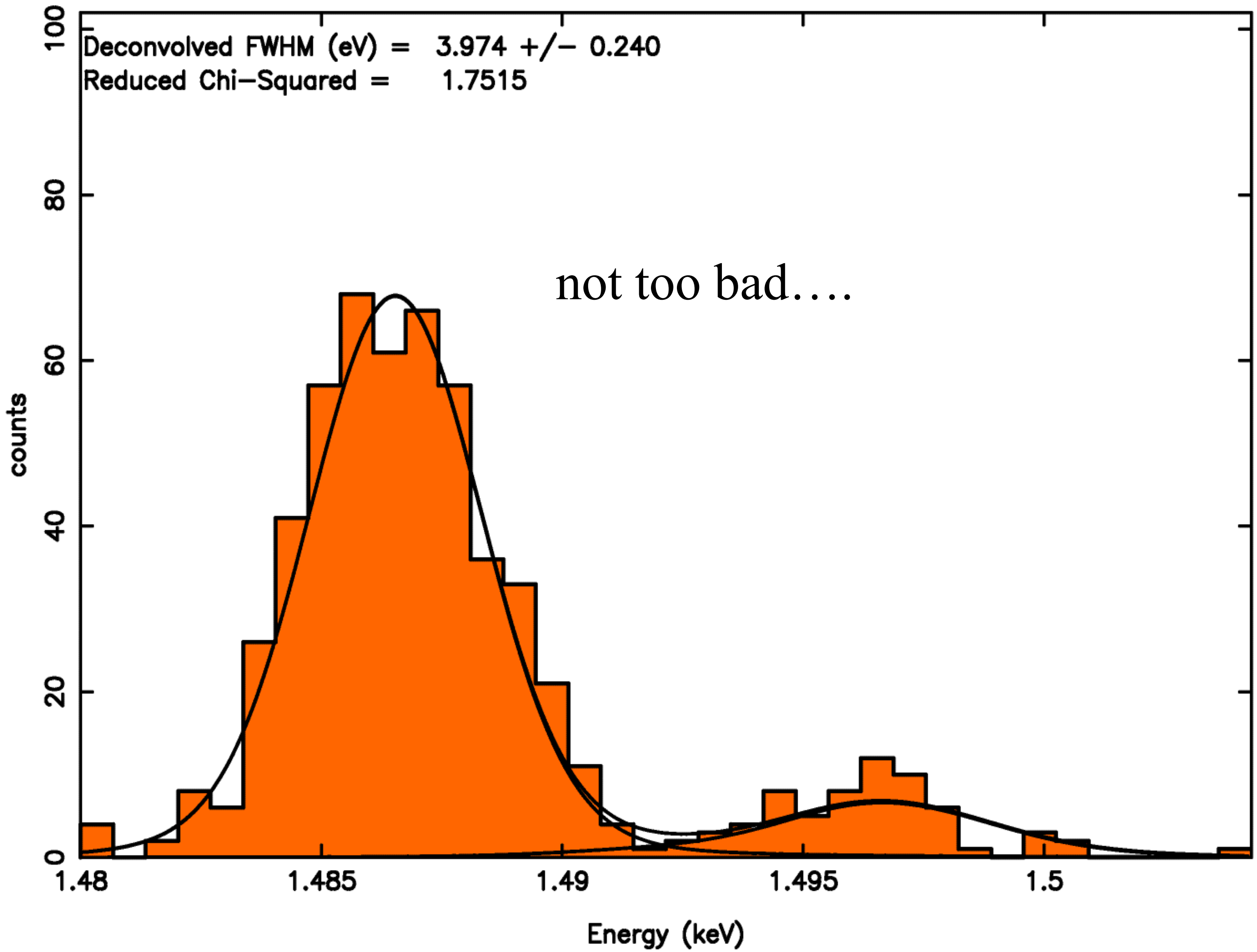

400 μm substrate
0.5 μm membrane
300 μm
5 μm slit

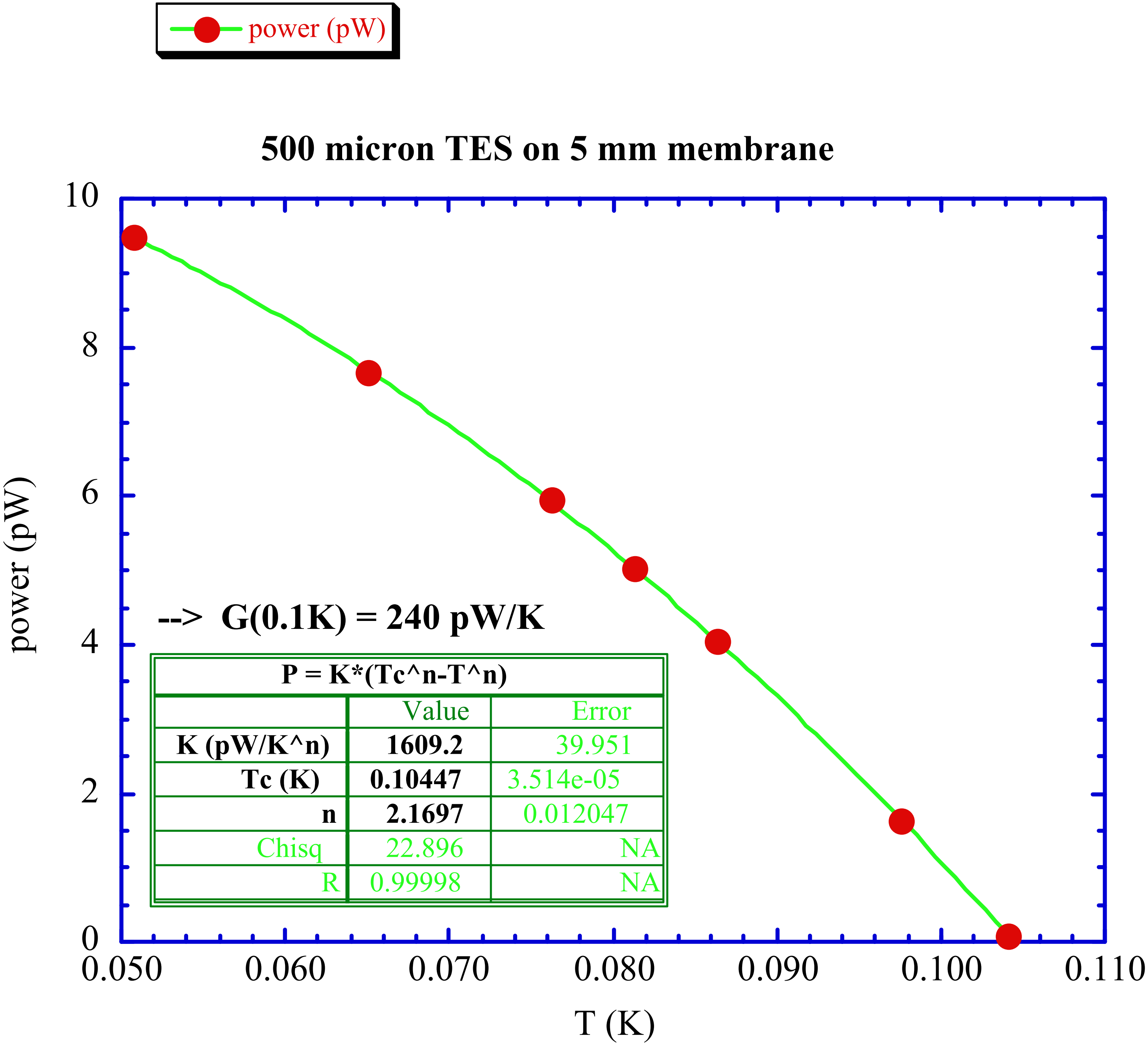


compact pixel power data
power (pW)
T (K)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.045
0.050
0.055
0.060
0.065
0.070
--> G(0.1K) = 60 pW/K
P = K*(Tc^n-T^n)
Value
Error
K (pW/K^n)
2980.8
698.37
Tc (K)
0.070182
2.2435e-05
n
3.2129
0.094996
Chisq
8.6573
NA
R
0.99993
NA

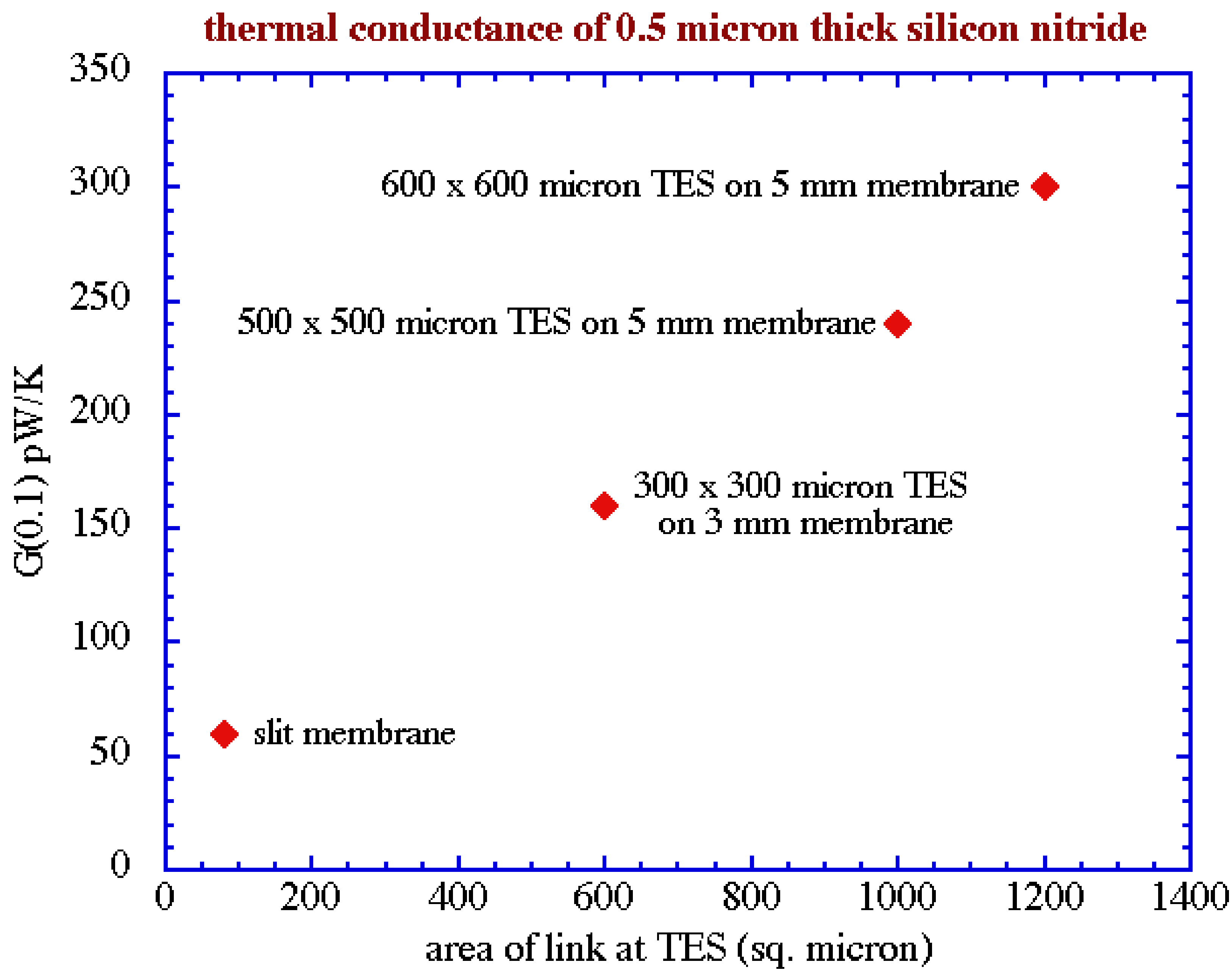
We also took some spectral data, but it was a quick data set. We didn't have time to optimize bias or reduce some bad pick-up noise.

Nonetheless….

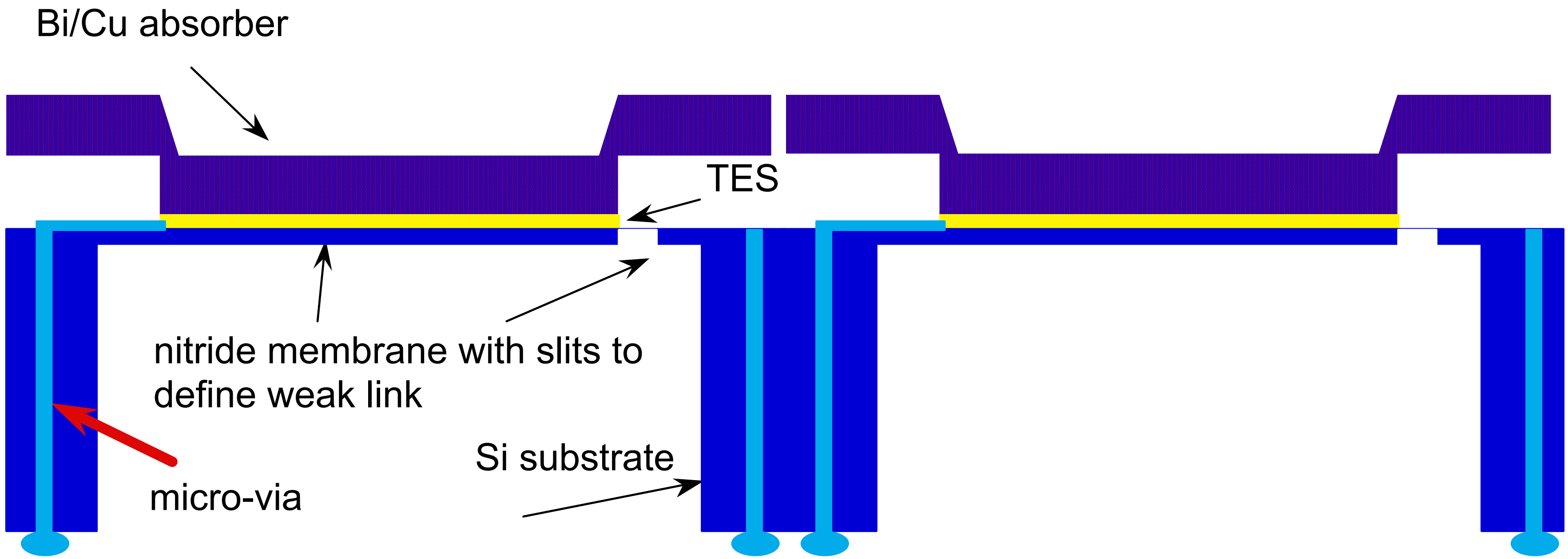

Deconvolved FWHM (eV) = 3.974 +/− 0.240
Reduced Chi−Squared = 1.7515
not too bad….
counts
Energy (keV)
0
20
40
60
80
100
1.48
1.485
1.49
1.495
1.5

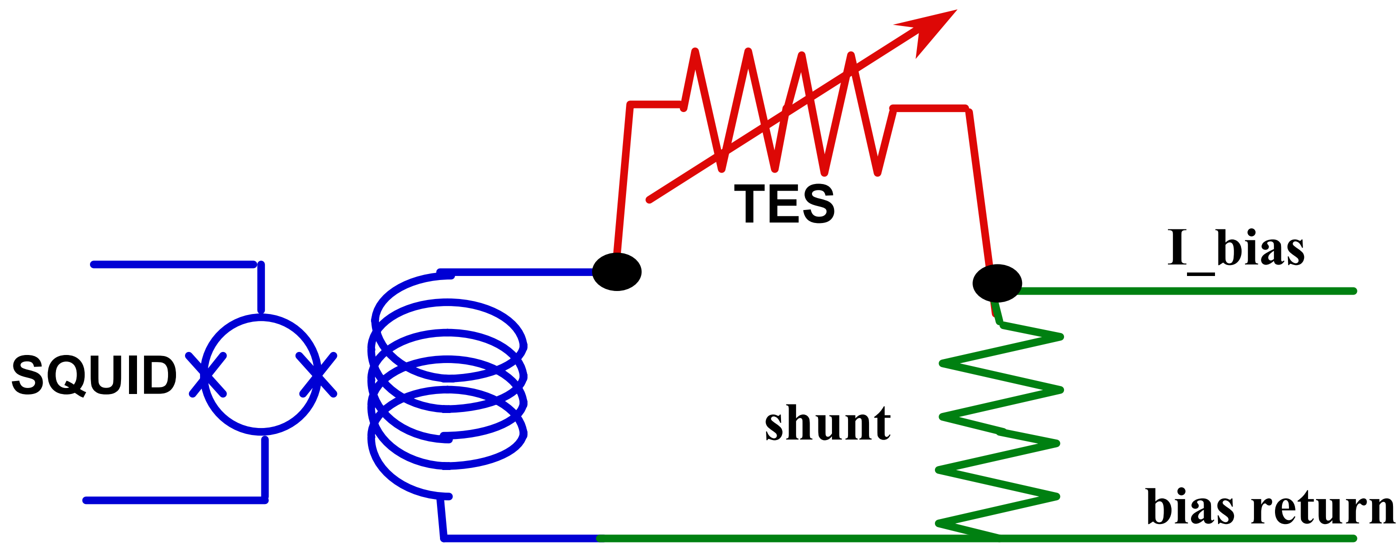


power (pW)
500 micron TES on 5 mm membrane
--> G(0.1K) = 240 pW/K
P = K*(Tc^n-T^n)
Value
Error
K (pW/K^n)
1609.2
39.951
Tc (K)
0.10447
3.514e-05
n
2.1697
0.012047
Chisq
22.896
NA
R
0.99998
NA
power (pW)
T (K)
0
2
4
6
8
10
0.050
0.060
0.070
0.080
0.090
0.100
0.110


thermal conductance of 0.5 micron thick silicon nitride
600 x 600 micron TES on 5 mm membrane
500 x 500 micron TES on 5 mm membrane
300 x 300 micron TES
on 3 mm membrane
slit membrane
G(0.1) pW/K
area of link at TES (sq. micron)
0
50
100
150
200
250
300
350
0
200
400
600
800
1000
1200
1400

idea for accommodating wiring layer:



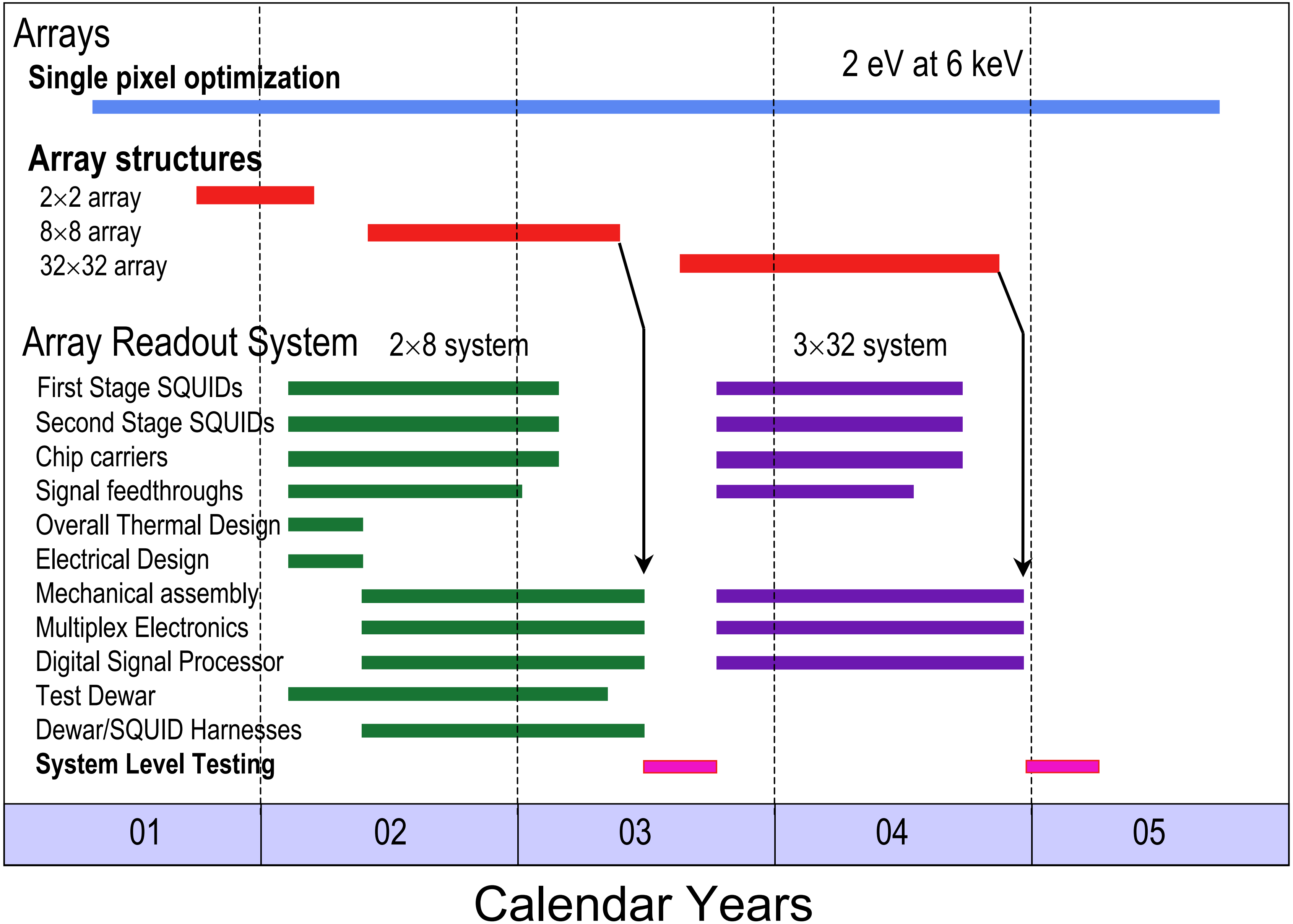


- We are independently studying the pieces that need to come together to make high-performance calorimeter arrays.

Short term plans:

- We will continue to learn from our single-pixel test devices and work to understand our noise sources.
- We will further study the scaling of the thermal conductance of the weak link and will determine the optimal geometry for both performance and ease of fabrication.
- We will test isolated compact pixels to understand how the geometrical constraints affect performance.
- We will continue to optimize close-packed, integrated, cantilevered absorbers.
- We will test small arrays in which all of these components come together.
- We will investigate methods for contacting pixels in a large array.

TES Microcalorimeter Development for *Constellation-X*



Clearly there is still much to do, but it looks like we have a path to Constellation-X scale pixels and arrays.